

# Orbiting spots and the measure of the Black Hole mass in AGN

***Giorgio Matt***

***(Dipartimento di Fisica,  
Università Roma Tre, Italy)***

# In collaboration with:

***Stefano Bianchi***

***(XMM-SOC, ESA, Spain)***

***Michal Dovčiak***

***(Acad. Sciences, Prague)***

***Vladimir Karas***

***(Acad. Sciences, Prague)***

***Matteo Guainazzi***

***(XMM-SOC, ESA, Spain)***

***Tomas Pecháček***

***(Charles Univ., Prague)***

# Black Hole Mass with iron $K\alpha$

Iron  $K\alpha$  reverberation mapping of structures in the line profile (Fabian et al. 1989, Stella 1990) or of integral quantities (EW,  $E_c$ ,  $\sigma$ : Matt & Perola 1992) has been proposed to measure the BH mass.

Extremely difficult technique:

It requires lots of photons ( $\rightarrow$  Con-X).

The Transfer Function is strongly geometry-dependent (the geometry of the illuminating source is largely unknown, differently to the case of optical reverberation mapping).

# Black Hole Mass with iron K $\alpha$

On the other end, if an iron line is emitted  
by a **small spot on the accretion disc**  
(corotating with the disc at the Keplerian velocity),  
the BH mass could be easily and precisely measured,  
once the radius is known.

A spot on the accretion disc at a radius  **$r$**  has an orbital  
period (as seen by an observer at infinity) given by

$$T_{orb} = 310 (r^{3/2} + a) M_7 \text{ sec}$$

where  **$M_7$**  the BH mass in units of  $10^7$  solar masses.

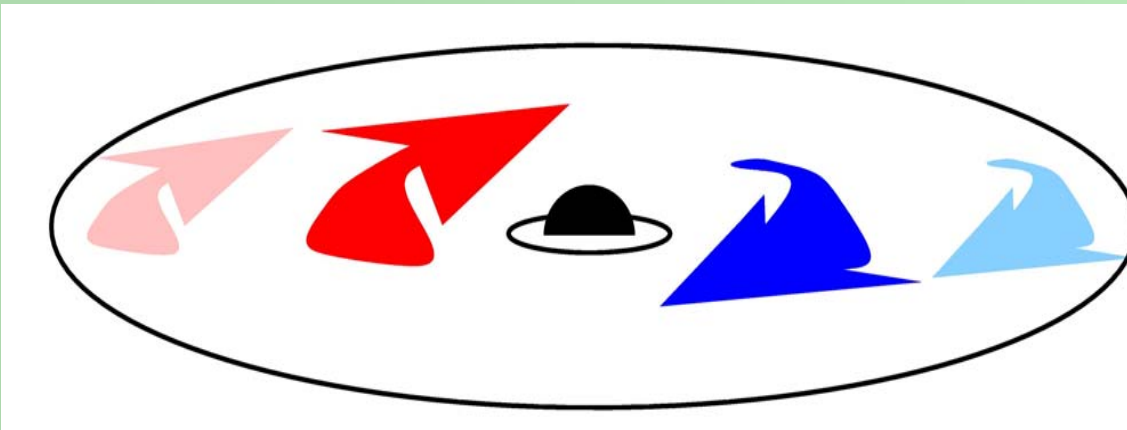
# Orbiting spots

If the spot radius and the BH spin can be estimated, **the measurement of the orbital period immediately provides the BH mass.** (The spin is relevant only for small radii.)

Let us assume a X-ray flare corotating with the disc.

X-ray illumination produces the iron line.

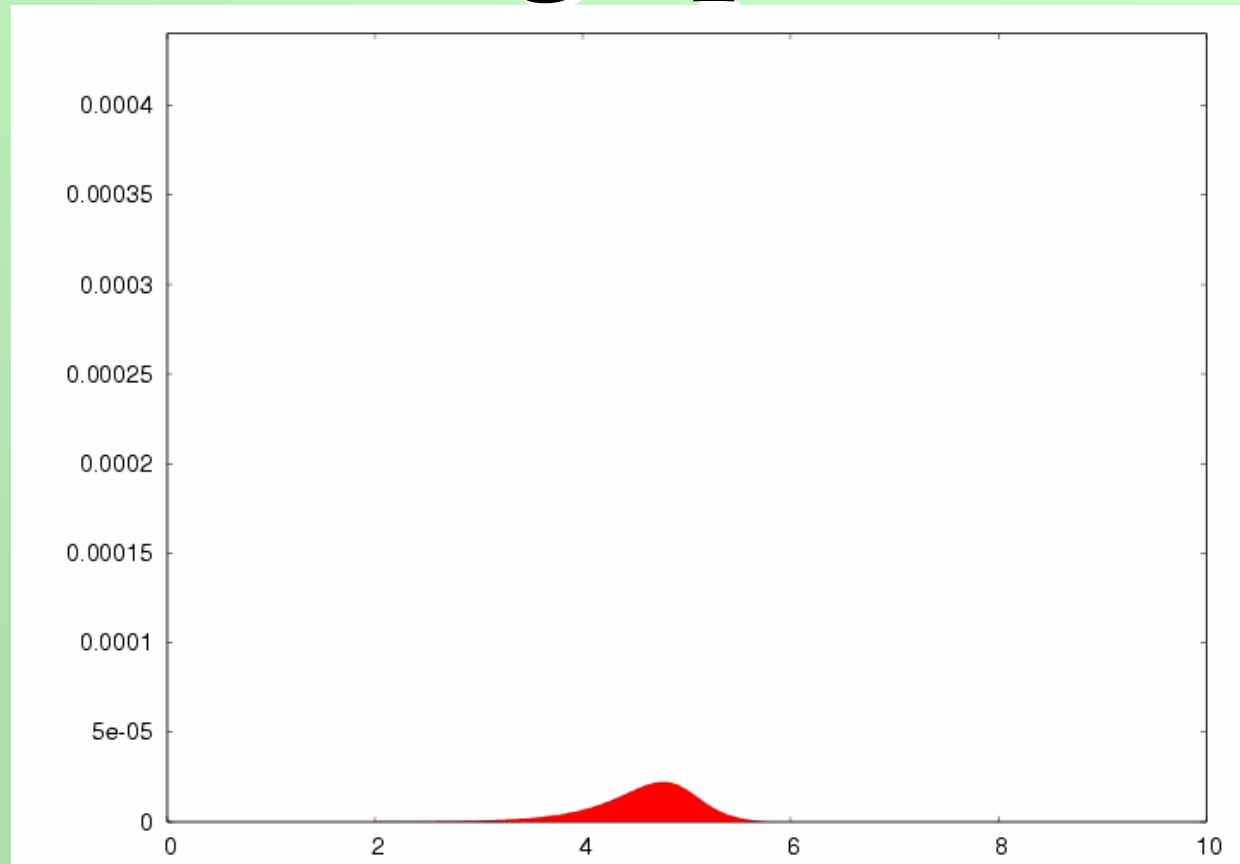
Due to Doppler shifting and boosting, the iron line gets *brighter and bluer* when the spot is approaching, *fainter and redder* when the spot is receding. These effects depends on the spot radius and the disc inclination.



# Orbiting spots

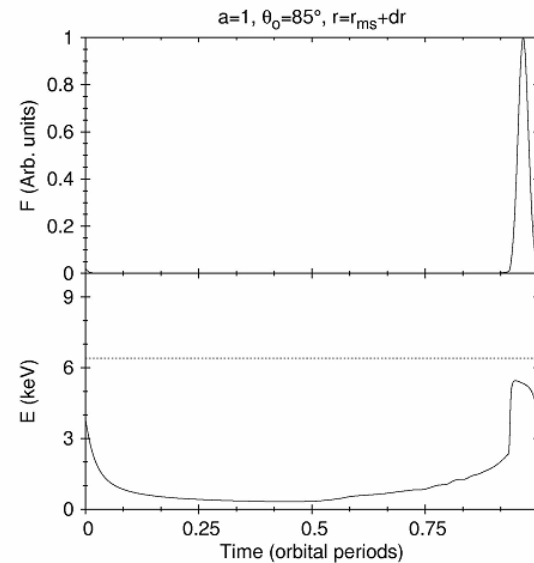
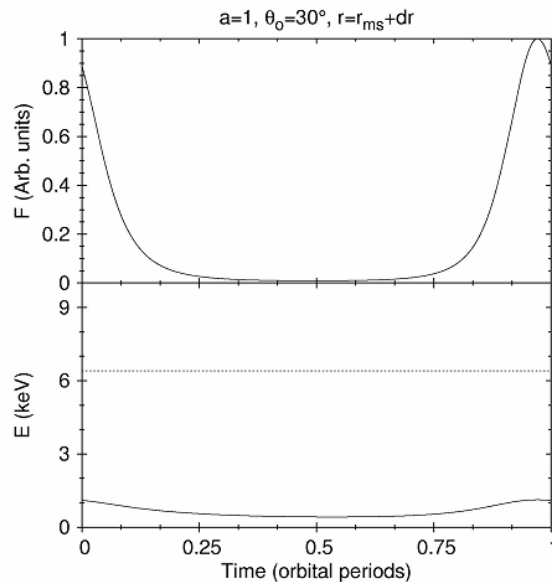
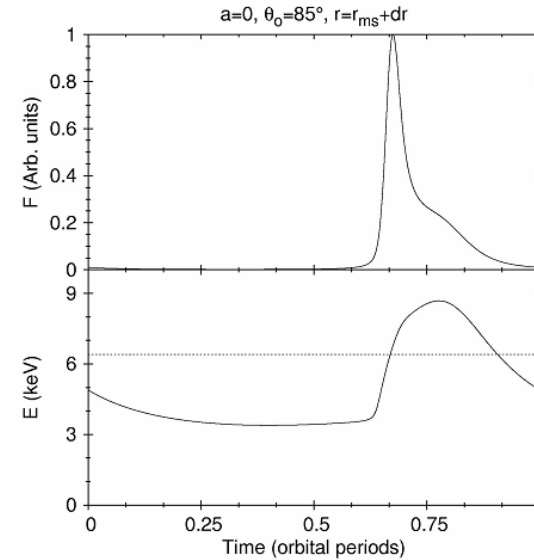
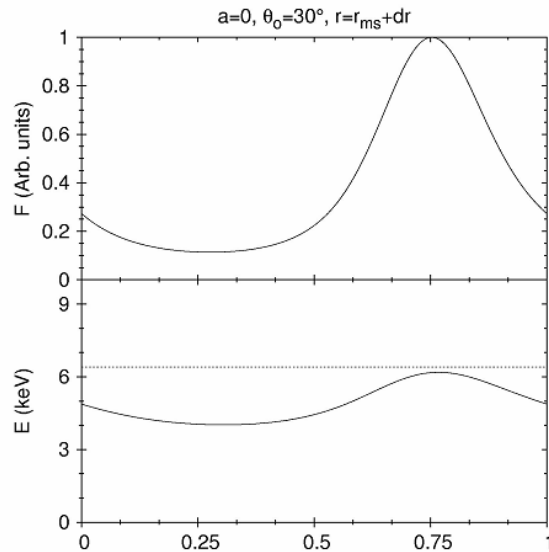
Line  
Flux  
(arb.  
units)

*Courtesy  
of  
M. Dovčiak  
& V. Karas*



# Orbiting spots

*Dovčiak  
et al.  
(2004)*



*$a=0$   
 $r=6$*

*$a=1$   
 $r=1$*

# Observational evidence

In a few Seyfert galaxies, narrow and faint (EWs of a few tens of eV) features between about 5 and 7 keV have been discovered by Chandra and XMM (in addition to the 'usual' iron lines):

**NGC 3516: Turner et al. 2002**

**ESO 198-G024: Guainazzi 2003, Bianchi et al. 2004**

**NGC 7314: Yaqoob et al. 2003**

**Mrk 766: Turner et al. 2004**

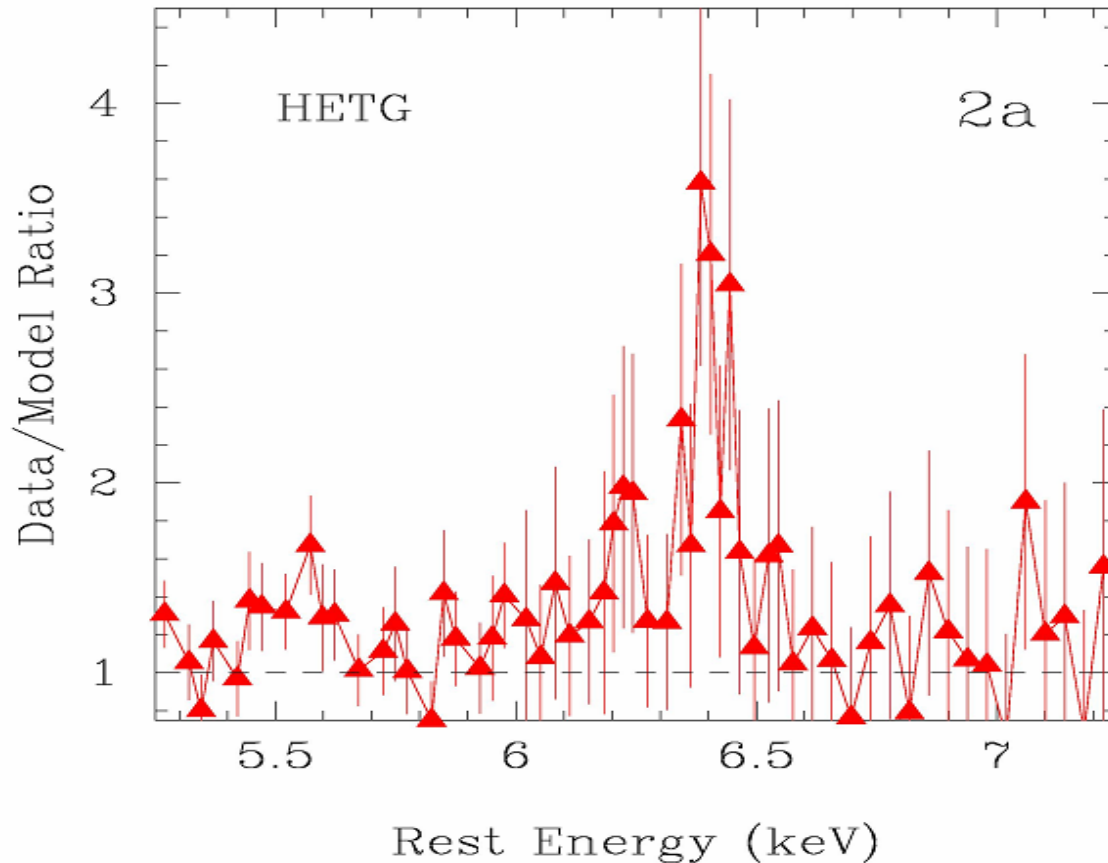
**Mrk 841: Longinotti et al. 2004**

**ESO 113-G010: Porquet et al. 2004**

**4U 1755-44: Piconcelli et al. 2006**



# Observational evidence



**Longinotti et al. (2005) recently performed a blind search for these features in a large sample of sources, and find a number of features significantly larger than expected by chance.**

**NGC 3516** (*Turner et al. 2002*)

# Interpretation

We (Dovčiak et al 2004) interpreted these features as the **blue peaks from orbiting spots**, the rest of the emission being below detectability.

(Note that for low radii and inclinations the “blue” peak may be redder than the rest energy)

This interpretation, even if by no means unique, is somewhat supported by the short term variability of some of these features.

Let us assume a **static ( $a=0$ ) BH** and derive the allowed ranges for the disc parameters

# Disc parameters

Source	$E_{line}$ [keV]	$r$ [ $GM/c^2$ ]	$\theta_0$ [deg]
NGC 3516	5.57	6–12	0–23
	6.22	6–50	0–35
	6.53	>6	20–40
ESO 198-G024	5.70	6–14	0–26
	5.96	6–21	0–30
NGC 7314	5.84	6–17	0–28
	6.61	>6	27–41
Mrk 766	5.60	6–12.5	0–24
	5.75	6–15	0–27
ESO 113-G010	5.40	6–10	0–20
4U 1344-60	5.31	6–9.7	0–18

*(adapted from Pecháček et al. 2005)*

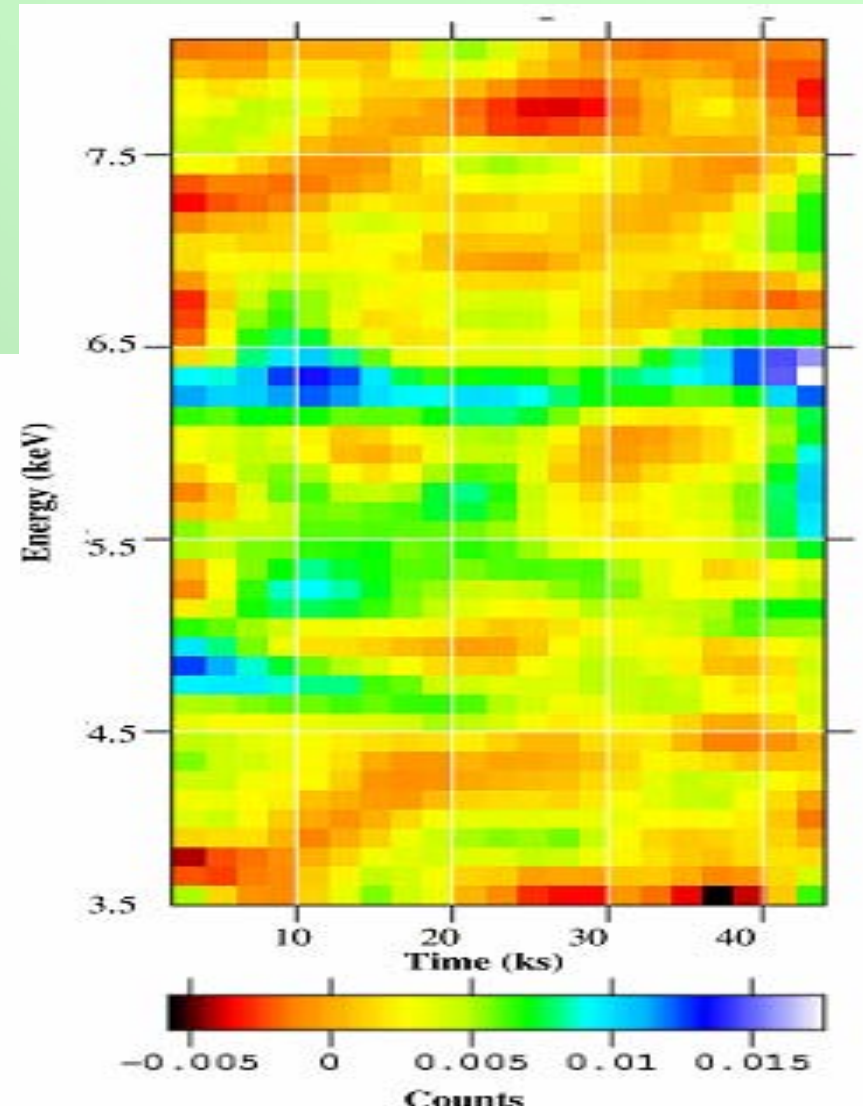
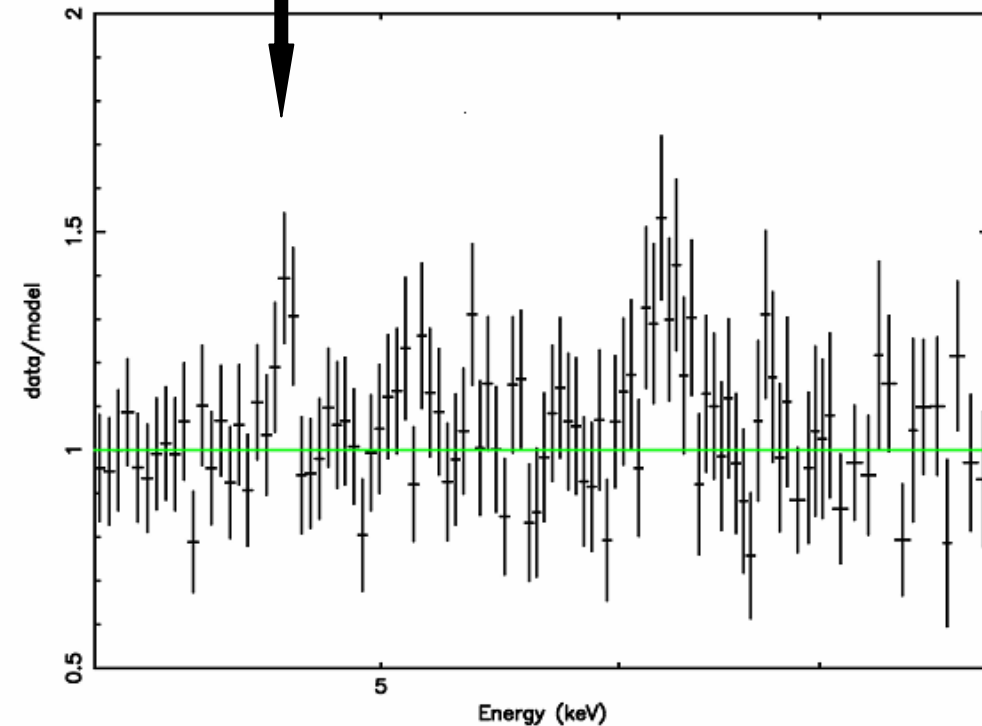
# Results

If this interpretation is correct, most of the features seems to come from small radii seen at relatively low inclinations. A solution consistent with  $a=0$  is always found. Allowing for  $a>0$ , even smaller radii (with higher inclinations) are possible (but, at present, not required).

Recently, a transient feature at **4.8 keV** has been found in Mrk 841 (Petrucci et al., in prep.). Its statistical significance is modest, so the detection is tentative. But if real, it would imply **a radius smaller than  $6 r_g$ , suggesting a spinning BH**

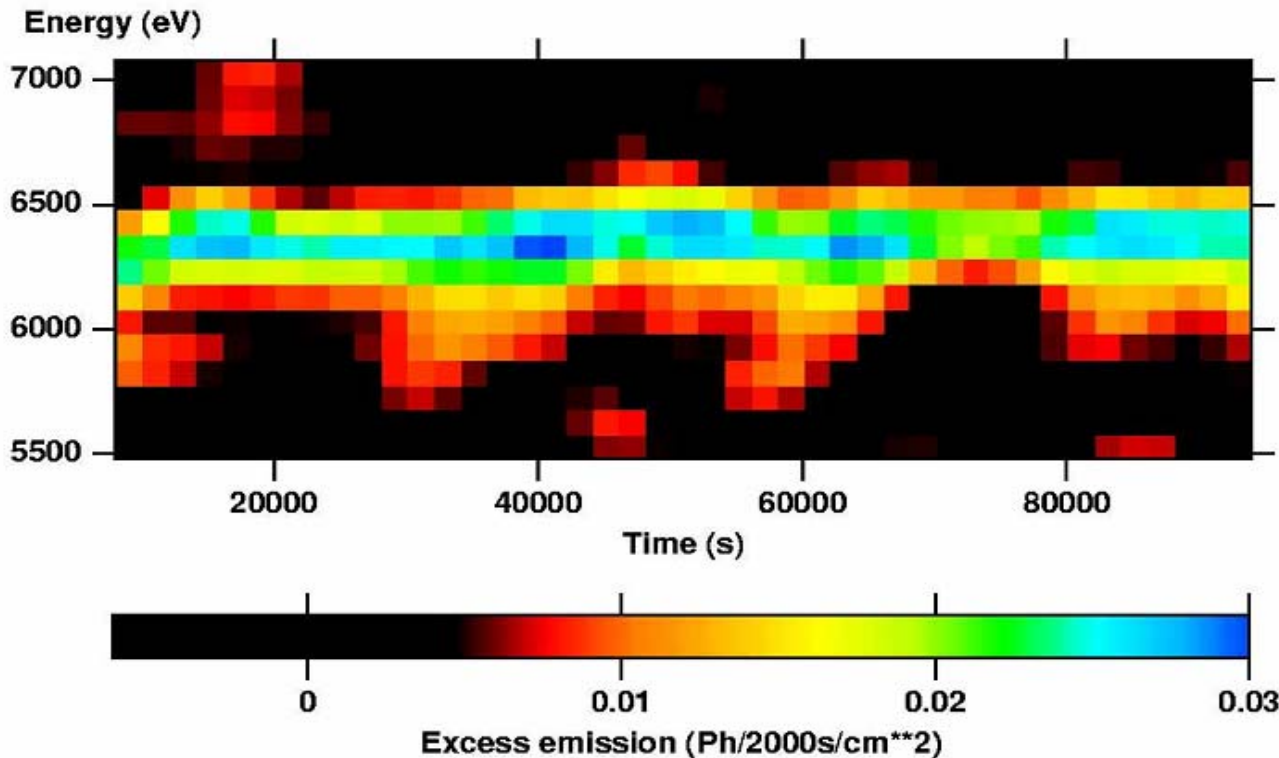
# Mrk 481

4.8 keV



# NGC 3516

Usually, these features cannot be followed along one or more orbits due to the too short observations, so the mass cannot be estimated. But there is one exception... **Iwasawa et al. (2004)** find in the XMM data of NGC 3516 evidence for a possible 25 ks periodicity of one of these features.



The derived  
BH mass is

**$1-5 \times 10^7$  solar  
masses**

consistent  
with other  
measurements

# Perspectives for Con-X

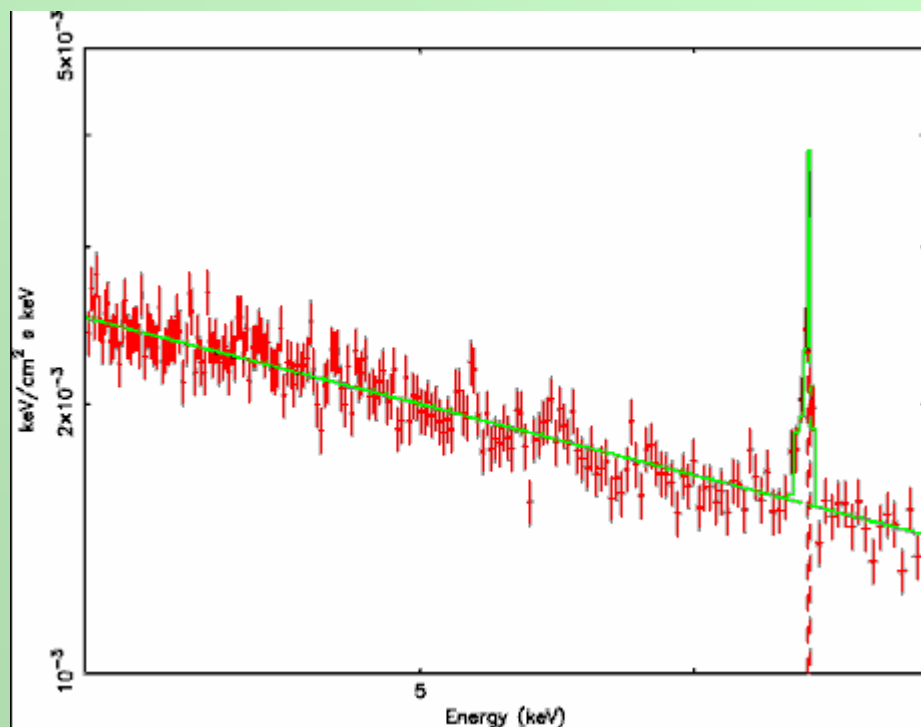
With the possible exception of NGC 3516,  
these features cannot be fully exploited to  
measure the BH mass.

For that, we would need many more  
**photons per unit time, i.e, much larger area**



## Constellation-X

# Perspectives for Con-X





# Perspectives for Con-X

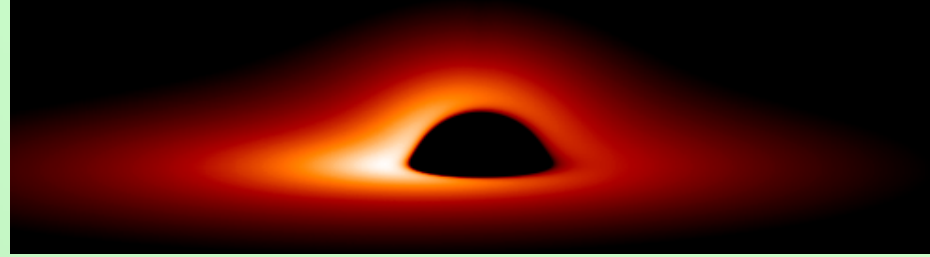
The precision with which the mass of the BH can be measured depends not only on the source flux and line EW, but also on the radius and inclination angle of the spot and on the BH mass itself.

In a mildly optimistic situation, i.e.

$r=10$ ,  $i=30$  degrees,  $M_{\text{BH}}=5 \times 10^7$  solar masses,  
 $\text{EW}=40$  eV,  $\text{Flux}=2 \times 10^{-11}$  cgs,

simulations show that, with the **baseline Con-X configuration**, the BH mass can be estimated with a precision of **about 40%** (comparable to the best optical reverberation mapping measurements)

# Summary



The narrow and transient features observed by Chandra and XMM-Newton in a few AGN may be interpreted as **iron lines from orbiting spots**.

In one case, NGC 3516 (Iwasawa et al. 2004), this is confirmed by the periodic variation of the feature, and the BH mass is estimated

## **Constellation-X**

will confirm these findings and measure the BH mass in the brightest AGN